Reflectarray element using interdigital gap loading structure

J.F. Li, Q. Chen, Q.W. Yuan and K. Sawaya

A novel reflectarray element using an interdigital gap loading structure is proposed. A wide reflection phase range of more than 1000° is obtained, which can support a sufficient phase range for a large scattering angle (up to 60°) reflectarray. Furthermore, this element has a feature of equal element size because the reflection phase is adjusted by controlling the finger length of the interdigital gap. Thus, abrupt geometry variations for consecutive cells in the traditional reflectarray can be avoided. A Ku-band reflectarray has been fabricated and measured results show good agreement with simulation.

Introduction: The reflectarray has been utilised in a wide range of applications for its advantages such as being surface-mountable, low mass and volume, easy deployment, and low manufacturing cost. The main aspect of designing a reflectarray antenna is to adjust the reflection phase for individual elements. Some phasing techniques have been reported such as using stubs, rotation, and variable size [1]. However, the stubs produce some dissipative losses and spurious radiation when bent. The rotation technique is only suitable for circular polarisation. Also, the conventional variable size methods require a geometrical difference of element size, thus the designed reflectarray usually involves abrupt geometry variations for consecutive cells. It has been shown that smoother variations lead to better performance [2]. Recently, identical size cells with a tunable varactor were used and achieved much success in the design of an electronically scanning reflectarray [3, 4]. However, for a fixed large scattering angle system, the control network and the lumped elements result in additional fabrication complexity, increasing fabrication cost and power loss owing to the varactor. The phase variation range is normally limited to less than 360° when using the tunable varactor.

On the other hand, for the design of a reflectarray, especially for a large scattering angle case, it is necessary to obtain any phase-shift value within a range of at least 360°. Furthermore, it has been demonstrated that a larger range of phase-shift is useful to improve the antenna bandwidth [5]. To achieve a larger phase range, the multilayer stacking technique has been used [6, 7], which leads to other shortcomings such as additional fabrication complexity, increased weight, and high loss.

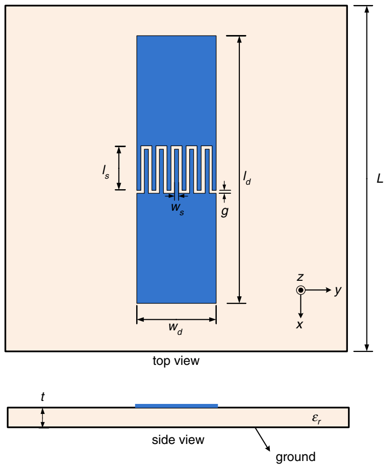

Fig. 1 *Geometry of interdigital gap loading element*

In this Letter, a novel reflectarray element, which is composed of a dipole with an interdigital gap structure printed on a single-layer substrate, is presented. A wide reflection phase range of more than 1000° is obtained by changing the finger length of the interdigital gap, while the total size of the individual dipole is kept the same. Furthermore, a reflectarray with a large scattering angle up to 60° is designed. The simulated and measured results for the prototype are presented and discussed.

Element design: The configuration of the proposed unit element is shown in Fig. 1. The dipole has length $l_d = 4$ mm and width $w_d = 1.2$ mm (at 24 GHz). The connection of two adjacent parts of the dipole constructs an interdigital gap structure, which is equivalent to a distributed fringe capacitor. By controlling the finger length, the capacitance loading is changed, which leads to different reflection phase. The length and width of each finger are l_s and w_s, respectively. The gap width between the fingers is 0.05 mm and the total size of the unit cell is $L \times L = 5 \times 5$ mm. In simulation, this unit cell is made on a substrate with relative permittivity $\varepsilon_r = 2.5$ and thickness $t = 0.75$ mm.

Fig. 2 gives the reflection phase of the unit cell against the length of fingers when the plane wave is incident normally to the element surface. This Figure demonstrates that a large phase range (more than 1000°) can be obtained by smoothly modifying the length of fingers, and the phase variation with the finger length is uniform with a change in frequency. The reflection phase is calculated using:

$$\phi_{\text{unit cell}} = \frac{\int_s \text{phase}(E_{scattered})ds}{\int_s \hat{s} \cdot d\vec{s}} + \frac{2\pi}{\lambda}h$$

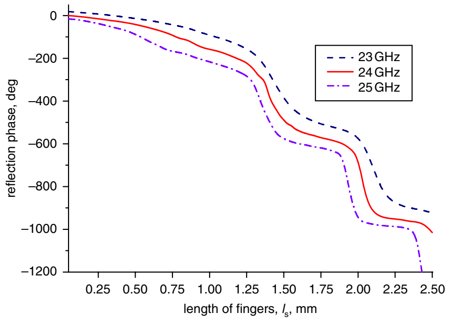

Fig. 2 *Reflection phase against length of fingers*

where $\vec{s}$ is the evaluated reflection plane, $\hat{s}$ is its normal unit vector and term h is the distance between the reflection plane and the surface of the dipole element, as defined in previous work [8].

It is noted that the design is very simple, as a single parameter (the finger length, l_s) defines the absolute phase shift; also, the total size of the dipole element is kept the same during the design procedure.

Array design: A 4 × 7-element reflectarray operating at Ku-band (12 GHz) with a scattering angle of 60° for normal incidence was designed and tested to validate performance. The geometry of the designed reflectarray is shown in Fig. 3 in rows and columns. Since the main beam is scanned only in the *xoz* plane, the dimension of the elements in each column is the same. The proposed structure was first simulated and optimised using the high-frequency structure simulation (HFSS), then a prototype was fabricated and the scattering pattern was measured in an anechoic chamber.

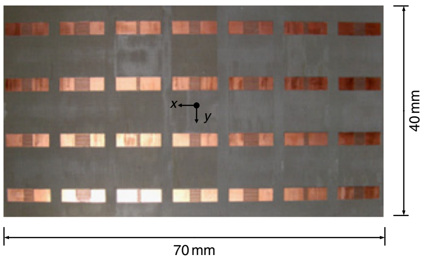

Fig. 3 *Photograph of fabricated reflectarray*

The simulated and measured scattering patterns of the proposed reflectarray at 12 GHz are depicted in Fig. 4, which shows good agreement. In our scattering measurement system, the scattering pattern cannot be measured at the scattering range of −15° to 15° for the normal incident because the receiving antenna blocks the incident wave from the transmitting antenna. Thus the measured data at this angle range is not shown in the Figure. A maximum directivity of 14.1 dB pointing at 58° is obtained, which agrees with the design angle well. Compared with the reflectarray in [8], abrupt geometry is avoided and improved scattering performance is achieved. The aperture efficiencies are 45.6 and 23.8% for the reflectarray in this Letter and that in [8], respectively. A −3 dB directivity-drop bandwidth of 13.1% is achieved. In the traditional reflectarray, practice is based on a ‘unit-cell' approach in which the phase of the scattered field is controlled locally by adjusting individually the geometry of each unit-cell. As shown in [2], smoother variations usually result in better performance. By using the proposed reflectarray element, smooth geometrical variations over the radiating aperture are preserved.

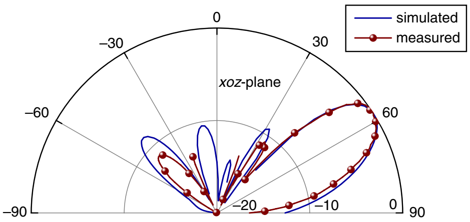

Fig. 4 *Scattering pattern of 4 × 7-element reflectarray*

Conclusion: Presented is a new reflectarray element, which exhibits an excellent phase range (more than 1000°). Moreover, abrupt geometry variations for consecutive cells are avoided because the total size of the dipoles are identical. Based on the proposed element, a large scattering angle reflectarray was designed to validate the performance. A maximum directivity of 14.1 dB and 58° scattering angle are obtained. The proposed reflectarray can be used to eliminate the blind spots of base station antennas in a downtown, high-building district and in other applications.

Acknowledgment: This research is partly supported by 'The research and development project for expansion of radio spectrum resources' of The Ministry of Internal Affairs and Communications, Japan.

3 November 2010
doi: 10.1049/el.2010.3083
One or more of the Figures in this Letter are available in colour online.

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